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Outcrop analogue study of Permocarboniferous geothermal sandstone reservoir formations (northern Upper Rhine Graben, Germany): impact of mineral content, depositional environment and diagenesis on petrophysical properties

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Abstract

© 2015, Springer-Verlag Berlin Heidelberg.The Permocarboniferous siliciclastic formations represent the largest hydrothermal reservoir in the northern Upper Rhine Graben in SW Germany and have so far been investigated in large-scale studies only. The Cenozoic Upper Rhine Graben crosses the Permocarboniferous Saar–Nahe Basin, a Variscan intramontane molasse basin. Due to the subsidence in this graben structure, the top of the up to 2-km-thick Permocarboniferous is located at a depth of 600–2900 m and is overlain by Tertiary and Quaternary sediments. At this depth, the reservoir temperatures exceed 150 °C, which are sufficient for geothermal electricity generation with binary power plants. To further assess the potential of this geothermal reservoir, detailed information on thermophysical and hydraulic properties of the different lithostratigraphical units and their depositional environment is essential. Here, we present an integrated study of outcrop analogues and drill core material. In total, 850 outcrop samples were analyzed, measuring porosity, permeability, thermal conductivity and thermal diffusivity. Furthermore, 62 plugs were taken from drillings that encountered or intersected the Permocarboniferous at depths between 1800 and 2900 m. Petrographic analysis of 155 thin sections of outcrop samples and samples taken from reservoir depth was conducted to quantify the mineral composition, sorting and rounding of grains and the kind of cementation. Its influence on porosity, permeability, the degree of compaction and illitization was quantified. Three parameters influencing the reservoir properties of the Permocarboniferous were detected. The strongest and most destructive influence on reservoir quality is related to late diagenetic processes. An illitic and kaolinitic cementation and impregnation of bitumina document CO2- and CH4-rich acidic pore water conditions, which are interpreted as fluids that migrated along a hydraulic contact from an underlying Carboniferous hydrocarbon source rock. Migrating oil and acidic waters led to the dissolution of haematite cements in the lower Permocarboniferous formations. During the Eocene, subsidence of the Upper Rhine Graben porosities and permeabilities of the sandstones of these formations were strongly reduced to 2.5 % and 3.2 × 10−18 m2. The second important influence on reservoir quality is the distinct depositional environment and its influence on early diagenetic processes. In early stage diagenesis, the best influence on reservoir properties exhibits a haematite cementation. It typically occurs in eolian sandstones of the Kreuznach Formation (Upper Permocarboniferous) and is characterized by grain covering haematite coatings, which are interpreted to inhibit cementation, compaction and illitization of pore space during burial. Eolian

sandstones taken from outcrops and reservoir depths exhibit the highest porosities (16.4; 12.3 %) and permeabilities (2.0 × 10−15; 8.4 × 10−16 m2). A third important influence on reservoir quality is the general mineral composition and the quartz content which is the highest in the Kreuznach Formation with 73.8 %. Based on the integrated study of depositional environments and diagenetic processes, reservoir properties of the different Permocarboniferous formations within the northern Upper Rhine Graben and their changes with burial depth can be predicted with satisfactory accuracy. This leads to a better understanding of the reservoir quality and enables an appropriate well design for exploration and exploitation of these geothermal resources.

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Keywords

Geothermal reservoir characterization, Germany, Outcrop analogue study, Permeability, Permocarboniferous, Porosity, Sandstone diagenesis, Thermal conductivity, Upper Rhine Graben